A STUDY OF THE BIOLOGY AND CONTROL OF THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* PERGANDE.

by

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Science at the University of Stellenbosch

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March 1996

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work, and has not previously, in its entirety or in part, been submitted at any University for a degree.

Date: 16/02/96

ABSTRACT

The effect of temperature on the development of *Frankliniella occidentalis*, Pergande on lima bean (*Phaseolus limensis*) leaf discs was investigated at five constant temperatures (15°, 18°, 22°, 25° and 30°C). Further studies examined the effect of temperature on reproduction and population growth at three constant temperatures (18°, 25° and 30°C).

Life table studies showed that adult longevity and developmental rate of each life stage were inversely related to temperature. The prepupal and pupal stages showed greatest sensitivity to temperature. The nett replacement rate (R_o) was highest at 25°C and the intrinsic rate of natural increase (r_m) highest at 30°C. The generation time (T) declined with an increase in temperature. Fecundity of females peaked at 25°C. The minimum threshold for development was found to be 8.9°C, and degree days for development ranged from 198.9 to 232.9.

Populations of male and female *F. occidentalis* were monitored over an 18 month period in a chrysanthemum glasshouse. Fluctuations in numbers of females were significantly correlated to temperatures both within and outside the glasshouse, while male numbers showed no correlation at any time. Males outnumbered females at low population densities. When high numbers of thrips were caught, females formed more than 65% of the trapped individuals.

The susceptibility of two strains of *F. occidentalis* to endosulfan and formetanate was tested in residue on-glass bioassays in the laboratory. Diagnostic doses resulting in approximately 50% and 90% mortality are proposed for endosulfan, namely 280 and 840 ppm a.i., respectively. Similarly diagnostic doses of 6 and 75 ppm a.i. are proposed for formetanate.

OPSOMMING

Die uitwerking van temperatuur op die ontwikkeling van *Frankliniella occidentalis* Pergande op boontjie (*Phaseolus limensis*) blaarskyfies is by vyf konstante temperature (15°, 18°, 22°, 25° and 30°C) bestudeer. Die effek van temperatuur op voortplanting en populasiegroei is ook by drie konstante temperature (18°, 25° and 30°C) bepaal.

Volgens lewenstabelstudies neem die ouderdom van volwassenes, sowel as die ontwikkelingstempo met 'n toename in temperatuur af. Die pre-papie- en papiestadia het die hoogste sensitiwiteit teenoor temperatuur getoon. Die hoogste netto vervangingstempo (R_o) is by 25°C verkry, terwyl die intrinsieke tempo van natuurlike toename (r_m) die hoogste by 30°C was. Die generasietyd (T) het met 'n toename in temperatuur afgeneem. Vrugbaarheid het die hoogste vertoon by 25°C. Die drempelwaarde vir ontwikkeling was 8.9°C, terwyl graaddae vir ontwikkeling tussen 198.9 en 232.9 gewissel het.

Beide geslagte van *F. occidentalis* is oor 'n tydperk van 18 maande in 'n glashuis, waarin krisante gekweek is, met behulp van geel kleefvalle gemonitor. 'n Betekenisvolle korrelasie is tussen die hoeveelheid wyfies wat gevang is en temperatuur gevind. Meer mannetjies as wyfies is in tye wanneer populasies laag was gevind. Wyfies het 65% of meer van die individue op die valle uitgemaak wanneer die populasies hoog was.

Die vatbaarheid van twee rasse *F. occidentalis* vir endosulfan en formetanaat is met behulp van glasplaat-residu toetse in die laboratorium bepaal. Diagnostiese dossise wat nagenoeg 50% en 90% mortalitiet tot gevolg gehad het, naamlik 280 en 840 dpm aktief, onderskeidelik, is vir endosulfan voorgestel. Diagnostiese dossise van 6 en 75 dpm aktief is, op dieselfde manier, vir formetanaat voorgestel.

ACKNOWLEDGEMENTS

I am indebted to the following:

* Professor J.H. Giliomee, Dr K.L. Pringle and Dr H. Geertsema for guidance and critical appraisal of the draft manuscript.

* Mrs M. van der Rijst (Agrimetrics Institute, INFRUITEC, Stellenbosch) for assistance in the interpretation of the statistical analysis.

* Mr A. Doorduin, manager of Oak Valley Flowers, for unlimited access to the glasshouses.

* The Viljoen and Van den Berg families of Môreson and Ebenhaezer Farms, respectively, for unlimited access to the farms.

* My husband Dick, and my family, for support, encouragement and suppers.

* My colleagues at Unifruco Research Services (Pty) Limited for making the burden lighter.

TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Origin and distribution

The western flower thrips, *Frankliniella occidentalis* Pergande, was first reported from the west coast of California on apricot and potato leaves, orange blossoms and various weed species (Pergande 1895). It was later reported on a wide range of crop hosts from other parts of the United States of America (Bryan & Smith 1956, Bibby 1958, Sakimura 1962, Beshear 1983, Bender & Morrison 1989, Pitblado *et al.* 1990). Presumably due to the increase in fresh plant material exports worldwide, the insect was discovered from 1980 onwards in glasshouse crops in countries in Europe, including Germany (Zur Strassen 1986), France (Bournier & Bournier 1987), the Netherlands (Mantel & Van der Vrie 1988), the United Kingdom (Oliver & Baker 1988), Finland (Kurppa 1989), Denmark (Brodsgaard 1989a) and Spain (Lacasa *et al.* 1992). It has since been reported from New Zealand by Zur Strassen (Brodsgaard 1989a), Israel (Argaman *et al.* 1989), Australia (Malipatil *et al.* 1993), and was identified on chrysanthemums from Namibia in 1991 (*pers. obs.*).

In South Africa it was first identified in 1987 (Giliomee 1989) when growers detected an "uncontrollable" thrips species in glasshouse crops in the western Cape Province and Gauteng. Subsequently, it has been found on several nursery and field-grown ornamental, fruit and vegetable crops (Daiber 1992, Badenhorst 1993, Gaum 1993).

1.2 Biology and morphology

Frankliniella occidentalis belongs to the order Thysanoptera (Greek: *thysanos* + *pteron* = a fringe + a wing). As with most species belonging to the suborder Terebrantia, *F. occidentalis* displays marked sexual dimorphism, with males being smaller and lighter in

colour than the females. The mouthparts of these insects are unique in that only one functional mandible is present in the post-embryonic stages, and the maxillae are reduced to a pair of elongate, asymmetric stylets that enclose a central channel through which food is drawn (Palmer *et al.* 1989). The insects feed by rasping, piercing and sucking plant material (Mound 1971).

F. occidentalis females have a saw-like ovipositor on the tenth abdominal segment with which a hole is drilled into the soft parenchyma tissue of leaves, fruit and flowers where eggs can be deposited. The post- embryonic development involves two larval instars, followed by a prepupal and a pupal stage, before the insect emerges as an adult. The whitish first instar larva emerging from the egg is almost invisible to the naked eye, and begins to feed soon after hatching. The waxy-yellow second larval instar, which emerges after the moult, feeds vigorously and is more active than the first instar. Once mature, the second larval instar displays positive thigmotaxis as well as negative phototaxis, moving away from light towards any object for shelter. In many thrips species all second larval instars fall to the ground to pupate under leaf litter (Grout *et al.* 1986), but *F. occidentalis* has been observed pupating in places that only provide shelter from light, for example against large veins on the underside of bean leaves (*pers. obs.*), and under artificial shelters provided for them on feeding substrate in the laboratory. Once a suitable place has been found, the larva moults once again and develops into the prepupa. In this stage wing buds start developing, and antennae lengthen slightly. Antennae are held rigidly in front of the head. Both the prepupa and the following stage, the pupa, are immobile, moving slightly or rapidly flicking the abdomen only if disturbed. The pupa emerges after a moult. The initial segmentation of antennae become evident during this stage; they are held folded over the head. Wingbuds increase in length. Both prepupal and pupal stages are pale yellow and do not feed. At the last moult the adult emerges. It is initially pale in colour, but becomes progressively darker within 48 hours of moulting (Brodsgaard 1989a). Shortly after emerging the adult starts to feed. The species is multivoltine (Bailey 1935).

Reproduction in *F. occidentalis* occurs by facultative parthenogenesis, being partly bisexual and partly parthenogenetic. Parthenogenetic reproduction in this species is always arrhenotokous in which unfertilised females lay eggs, which all develop into males, while most fertilised eggs develop into females (Brodsgaard 1989a).

Bryan & Smith (1956) identified three colour forms in *F. occidentalis*, and noted cold tolerance in the darker forms. Sakimura (1962) found darker individuals in spring, while the intermediate and lighter morphs were found in the warmer months of the year . This corresponds with findings in South Africa where the darker morph was found out-of-doors on various weed species during winter, and as temperatures became progressively warmer, trapped individuals were found to be lighter in colour (*pers. obs.*).

1.3 Behaviour

F. occidentalis is thigmotactic and is attracted to sheltered places. Complex flowers such as chrysanthemums offer ideal protection, and the insect can often be found deep within the flower head.

Contrasting results have been obtained in trials testing the attractiveness of colours to *F. occidentalis*. Moffit (1964) and Yudin *et al.* (1987) showed that adult *F. occidentalis* are more attracted to white than to yellow traps. Brodsgaard (1989b), however, found that this insect preferred various shades of blue, while other researchers found the response of *F. occidentalis* to blue significantly greater than to yellow (Fougeroux 1988, Robb & Parrella 1989, Gaum & Giliomee 1994). Vernon & Gillespie (1990a) found no significant differences in catches utilising fluorescent or non-fluorescent traps. They also reported that *F. occidentalis* was attracted to traps with increasing reflective intensity (Vernon & Gillespie 1990b). Matteson *et al.* (1992) found that adults displayed two peaks of spectral efficiency, namely in the ultraviolet range and in the visible range around 540nm (green). Further studies by Vernon & Gillespie (1995) showed that background colour and shape of traps

played significant roles in influencing trap catch of these thrips.

1.4 Host plants

F. occidentalis has been found to utilise up to 244 plant species from 62 families (Brodsgaard 1989a). In Europe *F. occidentalis* has mainly been found on crops grown under protection, with adults found only during the summer period on plants grown outdoors (Mantel & Van der Vrie 1988). In countries experiencing more temperate climates, this insect has been found infesting weeds and indigenous wild plants out of doors throughout the year (Chambers & Sites 1989, Stewart *et al.* 1989, Felland *et al.* 1993). This is also the case in South Africa (*pers. obs.*).

Unlike many thrips species which are mainly foliage feeders, *F. occidentalis* prefers pollen (Yudin *et al.* 1988). In a survey assessing the abundance of *Frankliniella* species on wild plant species in America, *F. occidentalis* numbers peaked at a time when the number of plant species in bloom was the greatest (Chellemi *et al.* 1994). They also found that *F. occidentalis* was more abundant on plants relative to other *Frankliniella* species and were present on the flowers in a greater proportion of the available plant species earlier in the season, leading to the assumption that *F. occidentalis* may displace other less harmful, indigenous thrips species under favourable conditions.

1.5 Damage

1.5.1 Direct damage

Direct damage by *F. occidentalis* can be caused to plants by the mouthparts of these insects during feeding, as well as by oviposition. These activities entail the perforation of plant tissues, including in many cases, the simultaneous injection of a chemical into the tissues and consequent cell lysis, and the removal of cell contents by sucking. As a result plant cells are left dehydrated and discoloured.

On ornamental flowers feeding by this thrips causes young petals to develop irregularly, and the scarring and silvering of older petals. On cucumber plants the thrips population is found on the leaves and fruit, with most adults found on the flowers (Rosenheim *et al.* 1990). Feeding damage to young cucumber leaves results in small necrotic spots which increase in size as the leaves develop and hamper the regular physiological processes of the plant.

Halo spotting (grapes) and pansy spotting (apples) are known to be caused by *F. occidentalis* ovipositing in very young fruit (Childs 1927, Madsen & Jack 1966, Yokoyama 1979). The discolouration of tissue surrounding an oviposition scar is unique to a deposited egg (Yokoyama 1977). In South Africa pansy spots were noticed as early as 1985, but at that stage not recognised as damage caused by *F. occidentalis*. When this was identified for the first time in 1990 (Badenhorst 1993), reports of similar thrips damage rapidly increased. Damage to certain varieties of table grape has also increased in the warmer, drier grape producing areas in recent years (*pers. obs.*)

Stonefruit is also susceptible to *F. occidentalis* attack (Yonce *et al.* 1990a, 1990b, Grasselly *et al.* 1993). Developing fruit is frequently damaged, as at this stage the fruit still features a very soft epidermis. Feeding damage develops into russeted lines and is found especially on the parts of the fruit where the senescing calyx is attached. Feeding damage also occurs when the fruit is about to be harvested when the epidermis has softened once again. Damage at this stage appears as silvered areas, where cell contents have been removed. It is also possible that *F. occidentalis* is one of a number of thrips species causing russet damage to nectarines in South Africa, as populations of this species are usually part of a wide range of thrips species present when fruit is susceptible to this type of damage (Badenhorst 1994). As the season progresses with accompanying rising temperatures, *F. occidentalis* populations increase in numbers. This species was observed causing feeding damage to nectarines in 1993 (*pers. obs.*) in a manner similar to that observed in Israel (Klein *et al.* 1993).

Other cash crops on which *F. occidentalis* damage has been observed include cotton (Watts 1937), onions (Bender & Morrison 1989), pepper (Fery & Schalk 1991), tomato (Salguero Navas *et al.* 1991), lettuce (Yudin *et al.* 1991), mango (Ben-Dov *et al.* 1992) and egg plant and watermelon (Latimer & Oetting 1994).

In most cases the presence of *F. occidentalis* is only noticed when damage is observed. Feeding sites of this insect usually appear as lighter areas on the plant surface. The dark blotches which frequently accompany these sites are faecal droplets deposited by feeding thrips.

1.5.2 Indirect damage

Thysanoptera feed by first injecting saliva into plant cells and then sucking up the contents of the destroyed cell (Tommasini & Maini 1995). This pattern of feeding ensures that thrips can acquire and transmit viruses. *F. occidentalis* has been found to transmit tobacco streak virus (Kaiser *et al.* 1982), impatiens necrotic spot virus (DeAngelis *et al.* 1993) and tomato spotted wilt virus (Sakimura 1962, Allen & Broadbent 1986, Marchoux *et al.* 1991). Testing for virus infection by means of the ELISA test found more than 50% of tested *F. occidentalis* to be infected by the tomato spotted wilt virus. The transmission of this virus by this species can occur with less than one-day-old larvae acquiring the virus, and 80% of larvae transmitting the disease before pupation (Tommasini & Maini 1995). Throughout their development the larvae usually remain on the same plant unless disturbed, and feed more or less gregariously, while the adults usually move around from plant to plant, and thus are of greater importance in disseminating disease than their larvae (Bailey 1935).

F. occidentalis was found to act as an agent for *Fusarium moniliforme* infections in maize plantings (Farrar & Davis 1991). There are also indications that it may lead indirectly to high botrytis infection on table grapes in the Western Cape by providing points of entry in the fruit epidermis for this fungus (*pers. obs.*).

1.6 Control

Recent literature stresses the fact that *F. occidentalis* has become resistant to many insecticides commonly used for the control of this insect. Difficulty in controlling *F. occidentalis* using insecticides is common (Fery & Schalk 1991, Immaraju *et al.* 1992, Brodsgaard 1994). Due to its hidden life style deep within host flowers, *F. occidentalis* is protected from the chemical sprays that the grower may use for its control. The frequent use of insecticides in glasshouse crop culture seriously limits the opportunities for using biological control agents against thrips as well as other mite and insect pests, as the biocontrol organisms are often detrimentally affected by pesticide applications. Suitable control measures for *F. occidentalis* are being investigated but progress has been disappointing. Biological control using various predatory mites, bugs, wasps and fungi has been investigated (Lindhagen & Nedstam 1988, Oetting & Beshear 1991, Van den Meiracker & Ramakers 1991, Loomans *et al.* 1992). The general conclusion is that this practice can be effective in protected environments, but less effective outside. Due to their apparent resistance to chemicals, *F. occidentalis* has the capacity to colonize niches left vacant by other thrips species which are eradicated when sprays are applied (Badenhorst 1994).

1.7 The present study

From the literature it is clear that *F. occidentalis* has become a global problem on a wide range of crops, grown both under cover and outdoors. The situation in South Africa is no different and this insect is rapidly expanding both its geographical and host plant range, making it necessary to study this insect locally for comparison to studies done elsewhere on its biology, population dynamics and susceptibility to chemicals.

This investigation comprises three chapters. Chapter 2 deals with life history parameters of *F. occidentalis*, Chapter 3 describes population dynamics of this insect within a

glasshouse, and Chapter 4 deals with the susceptibility of *F. occidentalis* to two insecticides; each chapter has been presented in the form of a scientific article.

As noted in the literature, life table studies have been carried out on various host plants to determine the effect of thrips on certain crops as well as the effect of the host plant on the reproductive capacity of this insect (Lublinkhof & Foster 1977, Lowry *et al.* 1992, Gaum *et al.* 1994, Van Rijn *et al.* 1995). However, to date no work has been published in which investigations were done to find a plant species which can be used to breed and culture thrips under laboratory conditions. Chapter 2 investigates life parameters for *F. occidentalis* on the leaves of lima bean (*Phaseolus limensis*) plants, which are easily obtained and cultured under laboratory conditions. The results are compared to life table studies obtained for *F. occidentalis* on other crops.

Chapter 3 presents the results obtained in a study in which populations of *F. occidentalis* were monitored over a two-year period in a chrysanthemum crop in a glasshouse. The aim of the study was to determine whether the artificial, regulated conditions within the structure influenced thrips abundance and population dynamics.

The impact of chemicals on *F. occidentalis* seems to be decreasing with more growers worldwide reporting control failures with a wide range of chemicals. In western Cape Province, chemicals are used to control populations of this insect on deciduous fruit trees. A report of the effect of two such chemicals is presented in Chapter 4 in which base-line data for two populations of *F. occidentalis* were collected. Diagnostic doses for these chemicals were proposed for future resistance monitoring. A method of testing the efficacy of chemicals under laboratory conditions is also investigated in this chapter.

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CHAPTER 2

LIFE TABLE PARAMETERS OF THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS*, (THYSANOPTERA: THRIPIDAE) ON LIMA BEANS (*PHASEOLUS LIMENSIS*).

2.1 ABSTRACT

Life table studies were undertaken for Frankliniella occidentalis (Thysanoptera: Thripidae) at five constant temperatures on lima bean leaves. The developmental time of each life stage as well as adult longevity was inversely related to temperature. The minimum threshold was 8.9 °C and the number of degree days needed to complete development was between 198.9 and 232.94 depending on temperature. The influence of temperature on reproduction was investigated at three constant temperatures. As temperature increased, females reproduced over a longer period of their life. The highest nett rate of reproduction was recorded at 25 °C. Generation times were inversely related to temperatures. Lima beans proved suitable as host plants for laboratory cultures of F. occidentalis.

2.2 INTRODUCTION

The western flower thrips, *Frankliniella occidentalis* Pergande, is distributed throughout North America as well as various European countries (Brodsgaard 1989). It was discovered in South Africa in 1987 (Giliomee 1989) and has since become, as in many countries, the predominant thrips pest of a number of greenhouse and outdoor crops in this country (Badenhorst 1994).

Since life table parameters differ for insects on different host plants as well as different plant parts (Brodsgaard 1989), the effect of temperature on developmental time and

reproductive rate of *F. occidentalis*, using lima bean leaves as a food source, was investigated. These studies complement similar studies done on wild radish leaves (Bryan & Smith 1956), green beans (Lublinkhof & Foster 1977), peanut foliage (Lowry *et al.* 1992), and cucumber leaves (Gaum *et al.* 1994, Van Rijn *et al.* 1995). Preliminary experiments using chrysanthemum leaves as a food source failed, as development did not progress further than the first instar larvae. Experiments later done by Van Dijken *et al.* (1994) showed that *F. occidentalis* caused damage to less than 20% of leaf area in over 10 chrysanthemum cultivars tested. The insects were mostly confined to emerging leaves in the absence of flowers. Since laboratory colonies of *F. occidentalis* are necessary for ongoing experimental purposes, the present trial was also used to indicate whether lima bean plants were suitable host plants for this insect.

2.3 MATERIAL AND METHODS

A colony of *F. occidentalis* was established on beans (*Phaseolus vulgaris* var. "Topcrop") in 1990 from various localities known to be infested with this insect. Identifications of specimens in the colony were verified by Dr R. zur Strassen (Senckenberginstitut, Senckenberganlage 25, Frankfurt, Germany), and voucher specimens are kept in the Department of Entomology and Nematology, University of Stellenbosch.

For the life table studies ten lima bean (*Phaseolus limensis*) leaves were placed adaxial surface up on moist blotting paper in a plastic container (330 x 220 x 65 mm). Fifty *F. occidentalis* adult females and 10 adult males were introduced from the colony onto the leaves with a small moistened camelhair brush (size no. 00). The container was then sealed with gauze netting (mesh size 104µ) and held at 22°C for 24 hours to enable the females to oviposit on the available plant material. Thereafter the insects were returned to the colony and the leaves held in an environmental chamber at one of each of five constant temperatures, namely 15°, 18°, 22°, 25° and 30°C. A temperature of 35°C was

found to be lethal to post-embryonic stages. The relative humidity ranged from 55-80% and a photoperiod of 16L:8D was maintained.

The leaves were checked every 24 hours for hatched larvae. These were placed individually on fresh lima bean leaf discs (22mm diameter) in petri dishes. The leaf discs were replaced every 3 days or less if warranted due to poor condition of plant material.

The developmental information of only those individuals surviving to adulthood is presented. Data on the developmental rates and longevity were collected at five temperatures (15°, 18°, 22°, 25°, 30°C) and data on fecundity were collected at three of the five temperatures, namely 18°, 25° and 30°C. Observations were made daily. To determine fecundity, the newly emerged adult females were placed individually in petri dishes and supplied with fresh leaf discs every 24 hours. A male from the colony was placed with each female for the duration of her life. Leaf discs removed from petri dishes containing ovipositing females were held at the respective temperature until hatching was complete. By recording transfer dates and the date of eclosion, incubation times could be determined without checking for eggs. Reproductive potential was thus determined on the basis of egg eclosion and not on the actual number of eggs deposited.

Life table calculations: Data on the survival and fecundity of individuals were combined in the form of a life table. The following parameters were calculated:

l_x: age specific survival or the proportion of individuals alive in age interval x.

m_x: age specific fecundity or the number of female progeny produced per surviving female in the age interval x.

Because the total daily progeny and sex ratios were known, rather than the actual number of progeny maturing as females, m_x was calculated using:

$$m_x = P.m_x'$$

where P = proportion of females, and

m_x' = total progeny produced per surviving female in age interval x.

The nett reproductive rate, R_o, was calculated using:

$$R_o = \Sigma l_x m_x$$

and the mean generation time, T, calculated using the formula:

$$T = \frac{\sum x l_x m_x}{\sum l_x m_x}$$

Life table components were used to calculate r_m, the intrinsic rate of increase, using the method described by Watson (1964). He describes the intrinsic rate of natural increase as "the rate of increase of a population under specified constant environmental conditions in which space and time are not limiting factors" and provides the following formula to be used in the computing of r_m:

$$\Sigma e^{-r_m x} l_x m_x = 1$$

Trial values of r_m were entered into the above formula until the value on the left-hand side differed from 1 by not more than 0.001.

The minimum developmental threshold temperature was determined by linear regression of the reciprocal of developmental time from egg to adult against temperature. The intercept of the line with the X-axis (temperature) provides an estimate of the minimum developmental threshold temperature (Wilson & Barnett 1983).

The number of degree days (°D) needed to complete development from egg to adult at each temperature was calculated using the following formula:

$$°D = (T - T_m) \times \text{days to develop from egg to adult}$$

where T = average temperature during development and

T_m = minimum developmental threshold derived from regression model

2.4 RESULTS

2.4.1 Influence of temperature on developmental time

Mean development time and percentage time of each stage are given in Table 1 for all stages of both sexes of *F. occidentalis* at five constant temperatures. Developmental time of each stage was inversely related to temperature. Significant differences ($P < 0.05$) were found in the rates of development of the two sexes only in the egg stage at 15°C, the pupal stage at 18°C and the larval stage at 25°C. Duration of the larval stage was the longest at all temperatures, and required between 36% and 45% of the total developmental time. The egg stage and combined pupal stages required approximately equal parts of the remaining period. Development time from egg to adult ranged from 10.9 (± 0.33) days at 30°C (female) to 34.7 (± 0.29) days at 15°C (male)(Table 1) but there were no significant differences between total male and female development time at any of the temperatures (Table 2). The minimum threshold for development was calculated to be 8.9°C (Fig. 1) and the number of degree-days needed for development from egg to adult ranged from 198.9 to 232.94 (Table 1).

Table 2. Developmental times for female and male *Frankliniella occidentalis*, with F-values and corresponding probability levels (P) at five constant temperatures.

Temperature (°C)	Females	Males	F	P
15	34.2	34.7	1.68	0.198
18	22.8	23.2	2.79	0.099
22	15.7	15.3	0.74	0.392
25	12.6	12.1	1.99	0.166
30	10.9	11.2	0.25	0.623

The regression line for the developmental rate on temperature for egg to adult is shown in figure 1. Regression lines for developmental rate on temperature for each immature life stage are shown in figure 2. The regression lines for the egg and larval stages were the same (intercept: t_{558} = 0.862, P=0.389; slope: t_{558} = 0.074, P=0.941), and data for the two stages were combined to form one line. The regression equation for each line is presented in Table 3. The rates of development of the prepupal and pupal stages increased more rapidly with an increase in temperature as compared to that of the combined egg and larval stages.

2.4.2 Influence of temperature on adult longevity

Adult longevity was inversely related to temperature (Table 1, Fig. 3a-e). At the two lower temperatures, namely 15° and 18°C, females lived significantly longer than males (P<0.05).

2.4.3 Influence of temperature on reproduction

Temperature altered reproductive parameters of *F. occidentalis* (Table 4, Fig. 3a, 3c, 3e). Mean fecundity (progeny per female) ranged from a minimum of 12.3 at 18°C to a

Table 3: Regression equations for rates of development for immature life stages and development from egg to adult of *Frankliniella occidentalis*.

STAGE	REGRESSION EQUATION	n	r^2
Egg + larva	y = -0.1085 + 0.0136x	660	0.64 (P<0.05)
Prepupa	y = -0.1316 + 0.0323x	330	0.37 (P<0.05)
Pupa	y = -0.5306 + 0.0427x	660	0.59 (P<0.05)
Egg to adult	y = -0.0418 + 0.0047x	660	0.91 (P<0.05)

maximum of 56.3 at 25°C. As the temperature increased, progeny was produced more rapidly. Fifty percent of the progeny were produced 13 days after eclosion at 18°C, 10 days at 25°C and 8 days at 30°C, i.e. females produced fifty percent of their progeny in the first half of their lifespan at 18°C increasing to the first 63% of their lifespan at 30°C. As the temperature increased, the reproducing period relative to the females' lifespan increased.

The proportion of females produced remained constant for the three temperatures, ranging from 42% to 46% (Table 4). The highest nett rate of reproduction (R_o) was 24.48 female progeny per female at 25°C (Table 4). At 18° and 30°C the corresponding R_o values were 5.11 and 17.2. Of the three temperatures tested the highest intrinsic rate of increase (r_m) was found at 30°C (0.1499). The generation time (T) declined with an increase in temperatures, ranging from 37.28 days at 18°C to 19.88 days at 30°C (Table 4).

Table 1. Duration of the developmental stages of *Frankliniella occidentalis* at five constant temperatures on lima beans (± SE), percentage time spent in each stage, adult lifespan and degree days necessary to complete development. *(S.E., n)

Temperature (°C)		15	18	22	25	30
Development time (days)						
Egg						
	F	9.0 (0.14, 41)*	6.22 (0.07, 32)	4.48 (0.14, 31)	3.85 (0.08, 20)	3.44 (0.24,9)
	% time	26.4	27.3	28.5	30.5	31.9
	M	9.7 (0.08, 48)	6.24 (0.07, 45)	4.74 (0.10, 69)	3.96 (0.11, 24)	3.72 (0.20,11)
	% time	27.9	26.8	30.0	32.6	33.3
Larva (1st & 2nd instars)						
	F	15.10 (0.21, 41)	9.78 (0.20, 32)	6.19 (0.40, 31)	5.30 (0.29, 20)	4.89 (0.26, 9)
	% time	44.2	43	39.4	42.1	44.9
	M	14.7 (0.21, 48)	9.84 (0.18, 45)	5.51 (0.24, 69)	4.58 (0.21, 24)	4.54 (0.3, 11)
	% time	42.2	42.4	35.9	37.8	40.7
Pronymph						
	F	3.2 (0.09, 48)	2.38 (0.12, 32)	1.81 (0.11, 31)	1.70 (0.11, 20)	1.0 (0.17, 9)
	% time	9.2	10.5	11.5	13.5	9.2
	M	3.1 (0.09, 48)	2.18 (0.10, 45)	1.90 (0.06, 69)	1.75 (0.09, 24)	1.27 (0.14, 11)
	% time	9.1	9.4	12.4	14.4	11.4
Nymph						
	F	6.9 (0.12, 41)	4.38 (0.11, 32)	3.23 (0.15, 31)	1.75 (0.14, 20)	1.57 (0.18,9)
	% time	20.1	19.3	20.6	13.9	14.4
	M	7.2 (0.14 48)	4.98 (0.09, 45)	3.17 (0.10, 69)	1.83 (0.17, 24)	1.64 (0.24, 11)
	% time	20.8	21.4	20.7	15.1	14.7
Egg to adult	F	34.2 (0.26, 41)	22.8 (0.22, 32)	15.71 (0.28, 31)	12.6 (0.28, 20)	10.9 (0.33, 9)
	M	34.7 (0.29, 48)	23.24 (0.21, 32)	15.32 (0.24, 69)	12.12 (0.2, 25)	11.18 (0.42,11)
Adult lifespan	F	30.9 (1.82,41)	24.2 (2.07, 32)	9.3 (0.96, 31)	15.8 (1.36, 20)	11.7 (2.2, 9)
	M	21.6 (1.44, 48)	16.7 (1.09, 45)	11.3 (0.78, 69)	14.0 (1.27, 24)	9.7 (1.39, 11)
Degree days		209.54	209.3.	203.31	198.9	232.94

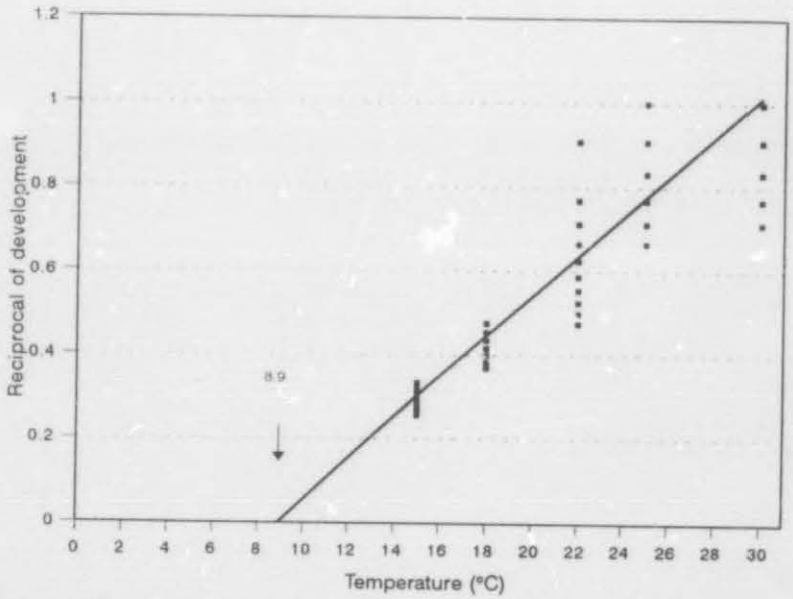

Figure 1. Rate of development in 1/time (days) of egg to adult *Frankliniella occidentalis* at five constant temperatures on lima bean (*Phaseolus limensis*) leaves.

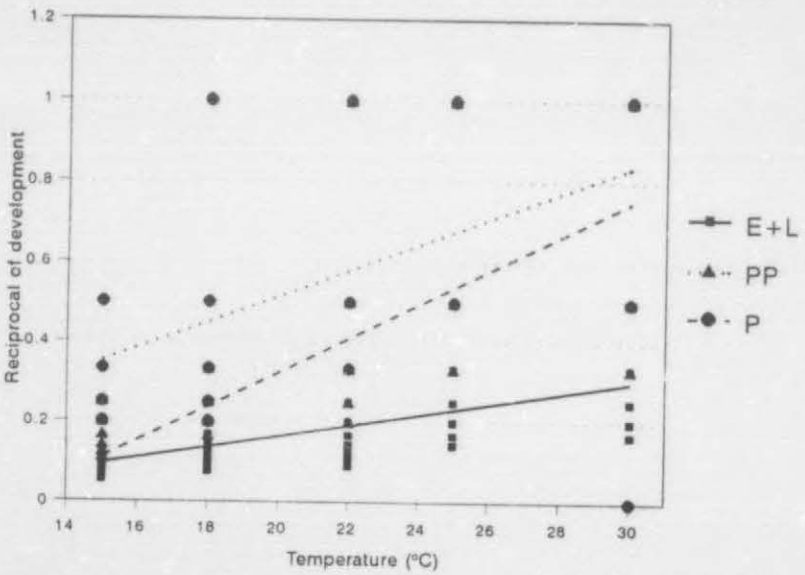

Figure 2. Rates of development in 1/time (days) of immature stages of *Frankliniella occidentalis* at five constant temperatures on lima bean (*Phaseolus limensis*) leaves. E+L = combined egg and larval stages, PP = propupal stage, P = pupal stage.

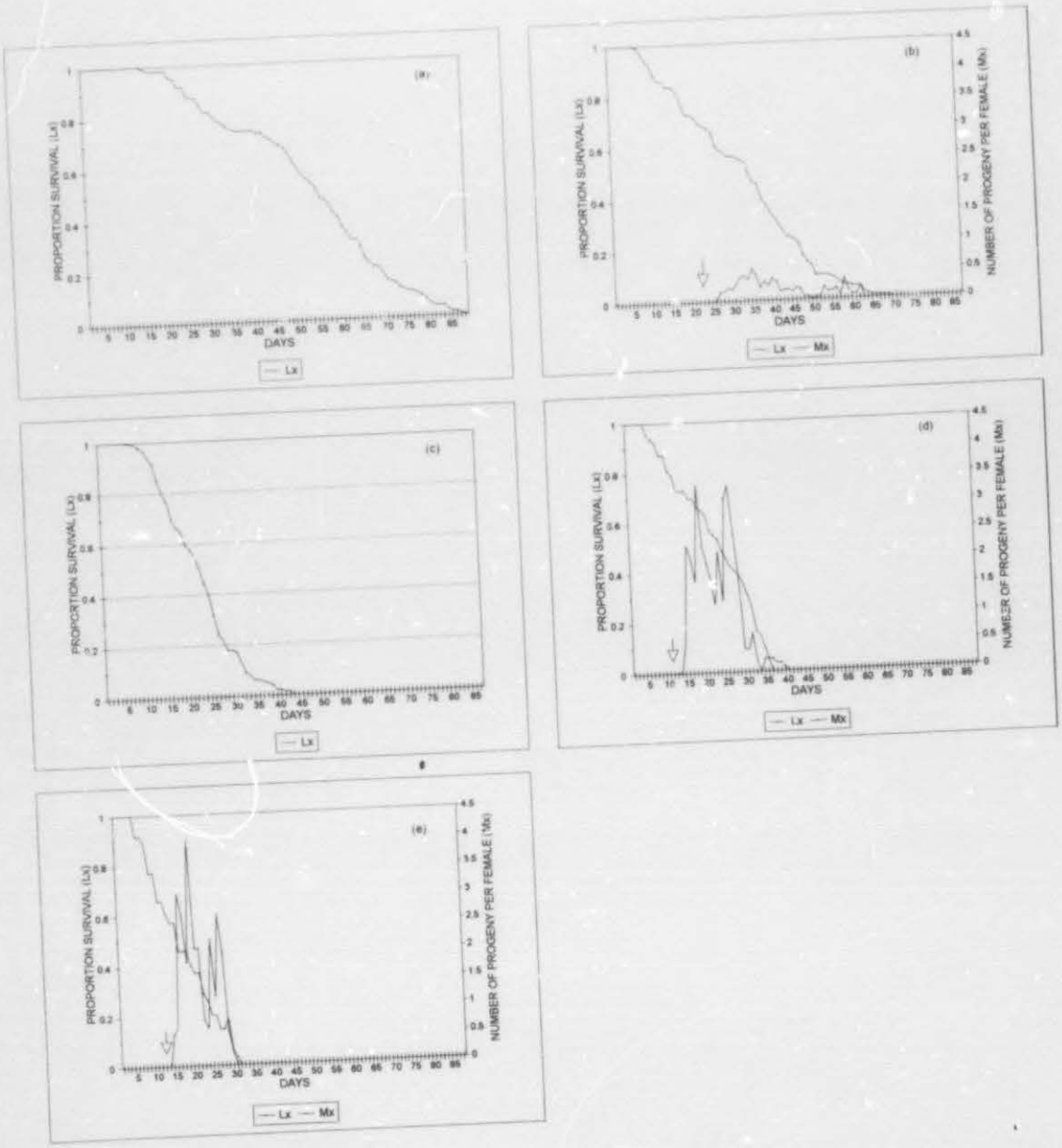

Figure 3. Age-specific survival [(a) - (e)] and age-specific fecundity [(b), (d) and (e)] of female *Frankliniella occidentalis* on lima bean (*Phaseolus limensis*) leaves. (↓ denotes date of emergence of adults).

Table 4. Reproductive parameters for *Frankliniella occidentalis* at three constant temperatures.

PARAMETER	TEMPERATURE (°C)		
	18	25	30
Average immatures per female	12.3	56.3	38.1
Range immatures per female	0-25	12-100	0-86
Nett reproductive rate (R_o)	5.11	24.48	17.2
Generation time (T)	37.28	22.64	19.88
Intrinsic rate of increase (r_m)	0.0451	0.1494	0.1499
Sex ratio (females/total)	0.42	0.46	0.45

2.5 DISCUSSION

The developmental time for *F. occidentalis* on lima bean leaves decreased with an increase in temperature (Table 1). This finding supports those observed in trials using radish leaves (Bryan & Smith 1956), green beans (Lublinkhof & Foster 1977) and cucumber leaves (Gaum *et al.* 1994, Van Rijn *et al.* 1995). At 15°C it was found that development from egg to adult for females took approximately 34 days on lima bean leaves. At the same temperature development differed between 48, 44 and 34 days on cucumber (var. Pipinex) leaves, radish leaves and green beans, respectively (Bryan & Smith 1956, Lublinkhof & Foster 1977, Gaum *et al.* 1994). At 30°C the corresponding time of development in this study was 11 days, compared to 13 days on green beans (Lublinkhof & Foster 1977). Gaum *et al.* (1994) reported that *F. occidentalis* completed its development from egg to adult on cucumber (var. Pipinex) leaves at this temperature in 11.5 days. Interestingly, Lowry *et al.* (1992) found that *F. occidentalis* showed 100% mortality at 30°C on peanut foliage. Teulon & Penman (1991) found that development time from egg to adult for female *Thrips obscuratus* was significantly longer than for males at five of seven temperatures ranging between 10° and 27°C, while in this study the

developmental time for females was faster than males at three of the five temperatures tested. None of these differences were found to be significant.

Gaum *et al.* (1994) and Van Rijn *et al.* (1995) found that eggs of *F. occidentalis* developed in 2.9 and 4.5 days at 25°C on the leaves of two varieties of cucumber, compared with 3.9 days on lima bean leaves in this study. In a study to determine the effect of resistant and susceptible cultivars of cucumber on the life history parameters of *F. occidentalis*, Soria & Mollema (1995) found that the duration of the egg stage was not affected by susceptible or resistant plant genotypes. The egg stage in their study lasted for between 3 and 3.3 days at 27°C, which compares favourably to the studies done by Gaum *et al.* (1994) and Van Rijn *et al.* (1995).

Table 1 displays the percentage time spent by *F. occidentalis* in each immature stage. The egg stage needed approximately 30% of the total time to develop, while the larval and combined pupal stages needed 41% and 29% of the remaining time, respectively. This was similar to studies on cucumber (var. Pipinex) leaves in which the egg, larval and pupal stages were completed in 30%, 45% and 25% of the developmental time, respectively (Gaum *et al.* 1994). The study by Van Rijn *et al.* (1995) showed a lower percentage time for the egg stage, and a higher percentage time spent in the pupal stages, i.e. 21% and 30%, respectively, on cucumber (var. Corona) leaves. However, on peanut foliage the egg stage was much longer, needing 46% of the total developmental time (Lowry *et al.* 1992). On cucumber (var. Pipinex) leaves the prepupal stage showed a greater sensitivity to temperature than the other immature stages (Gaum *et al.* 1994), while in this study on lima bean leaves, both the prepupal and pupal stages developed at a faster rate with increasing temperature when compared to the egg and larval stages. The prepupal and pupal stages are, due to their being sedentary and non-feeding, probably more susceptible to predation than other stages. It is therefore advantageous for these two stages to be more sensitivity to temperature than the other stages. Soria & Mollema (1995) found that, of all the

immature stages, the larval instars were most affected by the genotype of the host plant used.

The minimum threshold for development from egg to adult on lima bean leaves was 8.9°C (Fig. 1). Other authors found minimum development thresholds on various food plants ranging from 6.5°C to 10.4°C (Lowry *et al.* 1992, Gaum *et al.* 1994, Van Rijn *et al.* 1995). Degree days for development for all temperatures using $°D_{8.9}$ were found to range from 198.9 to 232.94 (Table 1). If a developmental threshold of 10°C was used, as by Robb (Lowry *et al.* 1992), the range was found to fall between 171 and 221. This is similar to results using 10°C as a common lower threshold for peanut (197°D), chrysanthemum (213°D) and radish (224°D). The low threshold temperatures for development for immature stages are consistent with the ability of *F. occidentalis* to exploit its many flowering hosts in spring as noted by Chellemi *et al.* (1994).

Mean adult longevity decreased with an increase in temperature (Table 1, Fig. 3a-e). Bryan & Smith (1956) noted that males have approximately half the life expectancy of females. In these studies it was found that males had up to 89% of the life expectancy of females, with slightly lower values at lower temperatures. This corresponds with findings of Bailey (1933) that males are shorter-lived and less resistant to colder conditions than females. At 15°, 25° and 30°C females lived for 30.9, 15.8 and 11.7 days respectively on lima bean leaves (Table 1), while on cucumber at the same temperatures they lived on average for 40, 13 and 10 days (Gaum *et al.* 1994). Increased longevity at lower temperatures indicates that *F. occidentalis* is able to survive mild winters in the western Cape Province. This is confirmed by the presence of this species, albeit in low numbers, on various plant species in fruit orchards during winter (Chapter 1).

The fecundity of F. *occidentalis* females (average immatures per female) showed a peak of 56.3 at 25°C. Fewer eggs are produced at lower and higher temperatures (Table 4). Lublinkhof & Foster (1977) reported 24.2, 95.5 and 43.3 offspring per female at 15°, 20°

and 30°C, with a peak at 20°C. Gaum *et al.* (1994) reported comparatively low numbers of eggs produced per female on cucumber leaves, ranging from 2.76 at 15°C to 10.65 at 30°C, with numbers constantly increasing as the temperature increased.

The nett replacement rate (R_o), defined as the number of daughters that will replace an average female in the course of a generation, has the value of 1 for a stable population (Price 1984). In this study the value of R_o varied from 5.11 at 18°C to 24.64 at 25°C, decreasing to 17.2 at 30°C (Table 4). Studies done by Lowry *et al.* (1992) on peanut suggest that peanut is a less favourable host, with R_o values of 1.08 and 2.25 at 20° and 25°C, respectively. Gaum *et al.* (1994) found that the R_o values on cucumber increased with temperature from 1.02 at 15°C (stable population) to 8.48 at 30°C. The studies by Van Rijn *et al.* (1995) showed that on cucumber (var. Corona) a relatively high R_o value, i.e. 22.1, was obtained at 25°C. They note that in the growth rate of a population, age is more important than nett reproduction rate as long as the R_o value is above 2.8 (i.e. an increasing population). In the present study reproduction at temperatures of 18°C and below would not depend on the age of the female, while this factor is of more importance at the two higher temperatures (25° and 30°C) tested. Fifty percent of offspring was produced earlier at higher temperatures, and it was found that females reproduced over a longer time under these conditions (Figures 3b, 3d, 3e). Thus the longevity of females which was higher at lower temperatures did not necessarily lead to higher numbers of progeny being produced.

The intrinsic rate of increase (r_m), or the rate of increase of a population growing under optimum conditions, was found to be 0.1494 at 25°C (Table 4). Van Rijn *et al.* (1995) reported an intrinsic rate of increase at 25°C of 0.16 for *F. occidentalis* on cucumber var. Corona. They used a prediction model in order to determine intrinsic rates of increase for *F. occidentalis* and *T. tabaci* on cucumber leaves, and found that peak rates of increase occurred below 30°C and diminished thereafter. The temperature-r_m curve obtained in the

present study compares favourably with this model, showing a rapid increase to 25°C with a diminished rate of increase thereafter.

The generation time (T), or the mean period of time over which progeny is produced (Price 1984), decreased with increasing temperatures. This corresponds with studies done on peanut foliage (Lowry *et al.* 1992) and cucumber var. Corona leaves (Van Rijn *et al.* 1995). This may add to the overwintering capacity of *F. occidentalis*, as offspring may be produced over a longer period of time at lower temperatures.

Brodsgaard (1989) reported that species of the genus *Frankliniella* reproduce by means of facultative parthenogenesis, namely partly sexual and partly parthenogenetic. The parthenogenetic reproduction is always arrhenotokous, with all unfertilized eggs developing into males, and most fertilized eggs developing into females. Brodsgaard further reported that fertilized females produced offspring in the ratio of 1 male: 6 females. The relatively constant proportion of females at each temperature in the present experiment , ranging between 42% and 46%, may be due to the low number of males in the original colony. As males and females were only confined together on leaf discs for a 24 hour period, it is possible that eggs of females within the colony had not been fertilized before the experiment.

This study showed that *F. occidentalis* populations increase in size more rapidly with an increase in temperature. Relatively short generation times at 25° and 30°C coupled with a relatively high reproductive potential at 25°C ($r_m \approx 0.15$) would provide the ideal situation for population build-up in areas with these average temperatures. Thus temperature is a very important factor affecting population densities of *F. occidentalis*. Decreased productivity at 18°C suggests that temperatures below 20°C may dampen population numbers.

Lima beans (*Phaseolus limensis*) were found to be a favourable host plant for *F. occidentalis*, and, because they require less growing space than cucumber plants, would be suitable for initiating and maintaining colonies of *F. occidentalis* under laboratory conditions. The plants proved easy to cultivate, needing a week from sowing to develop to a condition suitable for infestation by a population of thrips. The leaves provided large amounts of research material, necessitating the minimum number of propogated plants.

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CHAPTER 3

POPULATION DYNAMICS OF *FRANKLINIELLA OCCIDENTALIS* PERGANDE (THYSANOPTERA: THRIPIDAE) IN A CHRYSANTHEMUM GLASSHOUSE

3.1 ABSTRACT

Populations of the western flower thrips, Frankliniella occidentalis, were monitored using yellow sticky traps in a chrysanthemum glasshouse for a period of 18 months. Fluctuations in the number of females were correlated to temperatures measured within and outside the glasshouse. Male numbers trapped were not correlated to temperature at any time. Population peaks within the structure were similar to those of outdoor populations in nearby orchards.

3.2 INTRODUCTION

A small, but rapidly growing, percentage of the ornamental flower crop produced in South Africa is sold on overseas markets. This necessitates very stringent measures to eliminate the western flower thrips, *Frankliniella occidentalis* Pergande, from glasshouses in order to prevent cosmetic damage that can be caused by these insects. *F. occidentalis* has been recognised as a pest of ornamentals in southern Africa since it was identified in 1987 (Giliomee 1989). It is a polyphagous pest of a variety of crops worldwide (Sakimura 1962, Zur Strassen 1986, Vierbergen & Ulenberg 1988, Brodsgaard 1989a, Oliver & Baker 1988) and causes damage by feeding and ovipositing on soft parts of plants, leading to unsightly scarring and deformation. It is also a notorious vector of viruses affecting glasshouse crops (Allen & Broadbent 1986, DeAngelis *et al.* 1993). One such virus, the tomato spotted wilt virus, causes stunted growth, necrosis and eventual death of chrysanthemum plants if left unchecked.

Dissemination of this virus may occur rapidly in the presence of *F. occidentalis* populations, as contamination and transmission may occur within 24 hours.

Due to its cryptic behaviour *F. occidentalis* is difficult to detect in the initial stages of an infestation, making it difficult to determine the optimum time to apply control measures. The usually high degree of pesticide resistance of *F. occidentalis* populations (Immaraju *et al.* 1992, Brodsgaard 1994) further increases problems associated with its control.

Sampling by means of coloured sticky traps is a common method of monitoring adult thrips populations (Moffit 1964, Beavers *et al.* 1971, Brodsgaard 1989b, Grout & Richards 1990) and to obtain an idea of relative numbers of a pest in a given time in a given space (Heinz *et al.* 1992). Trap catches depend on population density and temperature which determines activity and reproductive potential (Frey *et al.* 1994). Effective population monitoring is essential for the timing of control strategies and to gauge their effect (Parrella & Jones 1985, De Klerk & Ramakers 1986), thus reducing applications of pesticides and increasing the efficacy of pesticides by improved timing (Heinz *et al.* 1992).

Yellow traps are attractive to many glasshouse pests, including both sexes of *F. occidentalis* at low population densities (Vernon & Gillespie 1990, Gaum & Giliomee 1994). Certain wavelengths are more attractive than others (Gillespie & Vernon 1990, Vernon & Gillespie 1990). Flat traps are more effective, and easier and cheaper to utilize than three-dimensional traps (Vernon & Gillespie 1995).

An understanding of the seasonal abundance of a pest species can be used to assess when economically damaging populations may occur (Salguero Navas *et al.* 1991). As *F. occidentalis* reproduces by means of facultative parthenogenesis, sex ratios within this species can give an indication of population trends. A population consisting

predominantly of females is considered to be increasing while when the ratio is biased towards males, the opposite is true (Anon. 1990). The major objective of this study was to examine the seasonal abundance and sex ratios of *F. occidentalis* on chrysanthemum over an extended period under commercial glasshouse conditions and to relate population fluctuations to conditions within the structure.

3.3 MATERIAL AND METHODS

Sampling was conducted in a commercial chrysanthemum glasshouse (9031 m² in size) located in the Grabouw area (34°12'S, 19°01' E). The chrysanthemums were grown according to recognised commercial practice. The crop was divided into 12 growth units (sections), each consisting of 12 beds (30m long, 1m wide). The glasshouse was under constant use, with one section being planted and another harvested simultaneously each week.

Beds of chrysanthemum (var. Snow Westland) were sampled. This variety was selected because of its lowered resistance to thrips attack observed by the local chrysanthemum grower. Rows were chosen systematically so that traps were distributed uniformly throughout the glasshouse. Estimates of thrips population densities were based on coloured sticky trap catches. Two yellow card traps (15cmx18cm) coated with a toxic sticky substance (Fly-Tac, Agricura, Nelspruit, South Africa) were hung on plant support wires 20 cm above the crop in each of twelve beds. This height was specifically chosen as the *F. occidentalis* catch on traps decreases exponentially from 0 to 250 cm above the tops of greenhouse grown African violet plants (Brodsgaard 1989b, Gillespie & Vernon 1990). Traps were changed and replaced fortnightly from July 1991 to December 1992. Removed traps were scanned under 80x magnification using a stereo microscope. Counts were made of all adult *F. occidentalis* caught on the traps, and the sex of each was determined. Counts presented are grouped into four-weekly trap catches on traps above each of 12 beds.

Temperature and humidity were measured within the glasshouse, and a weather station situated 50m from the structure recorded the external temperature. Pesticide treatments for the control of thrips were also recorded. Three compounds were used to control thrips on the crop. Because they were alternated irregularly throughout the trial period, they have been grouped collectively under "sprays". The glasshouse vents were regulated by computer, and these openings were also considered a factor enabling thrips to enter the structure.

3.4 RESULTS

In 1991 adult *F. occidentalis* were trapped throughout the sampling period (July to December). The number of *F. occidentalis* per trap fluctuated during this time (Fig. 1a). The average relative humidity ranged between 77 and 91%, and average temperatures inside and outside ranged from 11.4 - 20.6°C (Figure 1b).The internal temperature was regulated and did not fluctuate as much as the external temperature. The ratio of females to males also varied over time. At high densities of thrips the ratio of females to males was higher than when thrips were trapped at low densities. The number of females trapped was significantly correlated to temperature within the structure ($P<0.05$), and significantly negatively correlated to relative humidity ($P<0.05$). Male numbers showed no correlation to the measured climate parameters ($P>0.05$).

In 1992 numbers of both sexes fluctuated (Fig. 2a). Males were found in greater numbers during the colder months of the year. Significant positive correlations were found between numbers of females and both the internal and external temperatures ($P<0.05$), and a significant negative correlation was found between female numbers and relative humidity ($P<0.05$). No significant correlations were found between male numbers and any parameter measured (Fig. 2a & 2b).

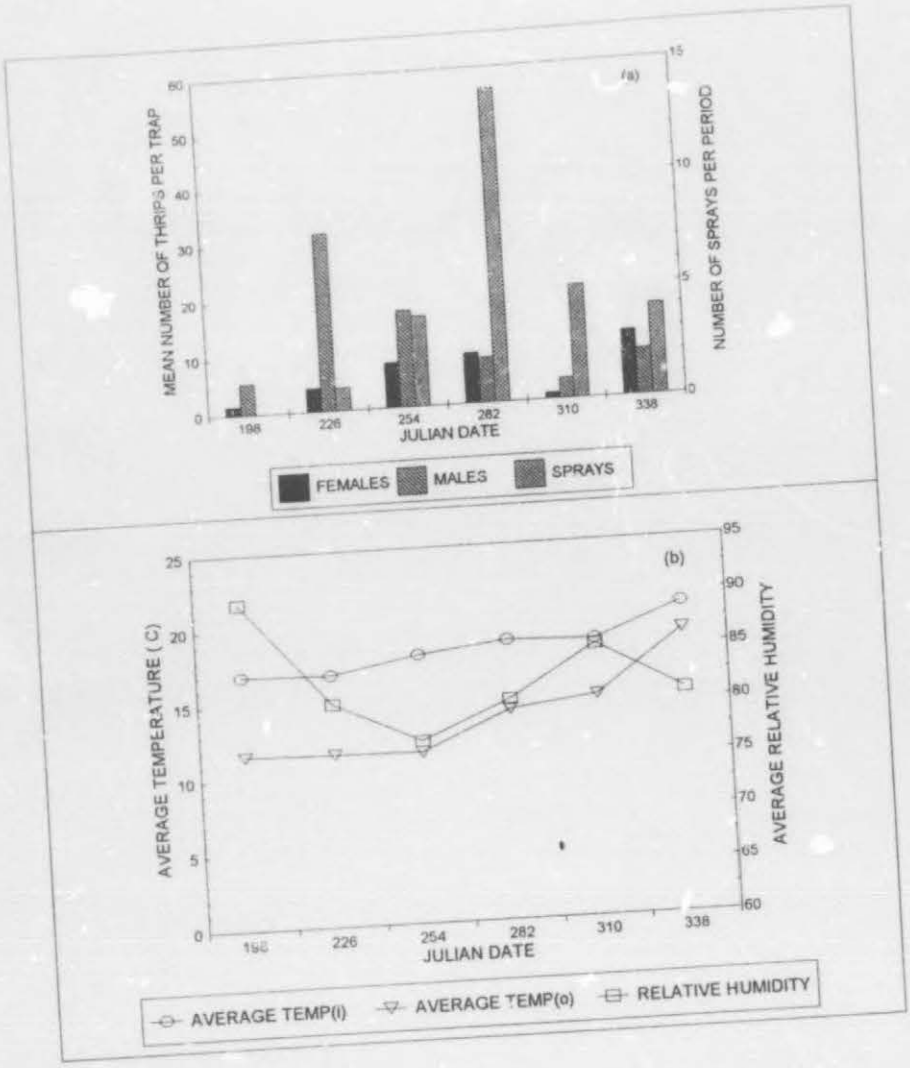

Figure 1. Data presented for four-weekly periods for (a) mean number of female and male *Frankliniella occidentalis* per trap and sprays applied, and (b) measured average temperature (inside and outside) and relative humidity in a chrysanthemum glasshouse in 1991.

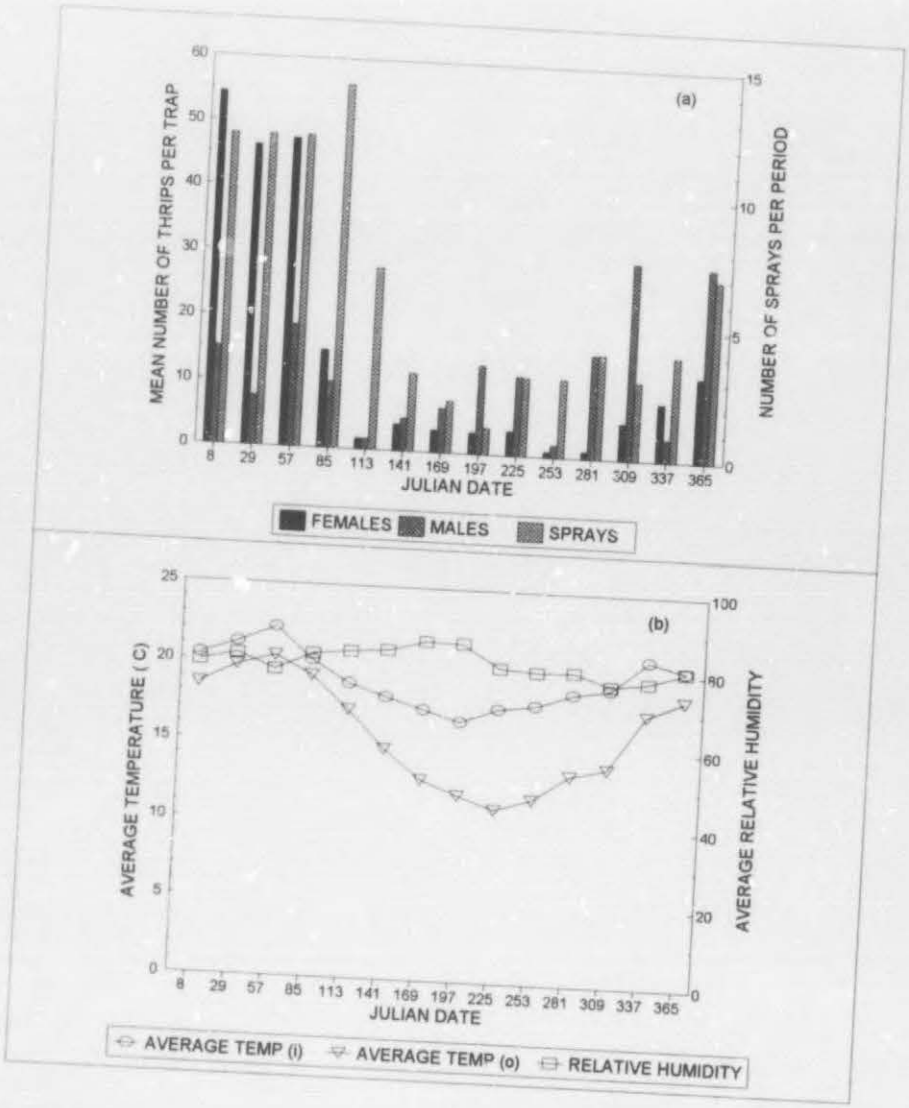

Figure 2. Data presented for four-weekly periods for (a) mean number of female and male *Frankliniella occidentalis* per trap and sprays applied, and (b) measured average temperature (inside and outside) and relative humidity in a chrysanthemum glasshouse in 1992.

In 1991 sprays were applied routinely, while in 1992 the grower applied sprays in accordance with trap catches of thrips. A higher number of sprays was applied for the control of thrips earlier in the season in 1992 than in 1991, and female numbers did not build up as rapidly as in the previous year. Male numbers were also not as high as the previous year.

3.5 DISCUSSION

As continuous cropping was practiced in the glasshouse, the thrips population trends cannot be related to crop phenology. Both sexes of *F. occidentalis* were found in the glasshouse throughout the year. The population dynamics of males and females differed throughout this period. Males were seemingly not affected by climatic conditions while female numbers correlated positively with temperature. The negative correlation with relative humidity (Fig. 1 & 2) is probably explained by the fact that an increase in temperature is often accompanied by a decrease in relative humidity. High humidity has been found to decrease thrips populations (Hall 1932, Harding 1961). At low population densities males outnumbered females (Fig. 2a), while at high population densities (e.g. days 29 and 57 in 1992) females formed more than 65% of the trapped individuals. This is in agreement with studies carried out by Higgins & Myers (1992). The high ratio of males at certain times of the year may also be attributed to the theory put forward by Terry & Kelly (1993) that males may disperse and fly more readily than females. By investigating the sex ratio of adults on sticky traps, "hot spots" may be detected and control measures applied locally rather than throughout the glasshouse. With the knowledge that high populations of males often preceed high numbers of females within a given area, growers may, by effective monitoring, be made aware of the potential outbreak of these insects, and be able to react before the population increases to unmanageable proportions.

In the life history study of *F. occidentalis* presented in Chapter 2, it was found that as temperatures rose, females were more fecund. Mated females produced more eggs than unmated females (Higgins 1992). This explains the sudden rise in numbers of this pest as temperatures become more favourable. Higgins & Myers (1992) suggested that male availability may be the most important factor affecting the number of daughters produced by individual females. At low temperatures females were found to live longer. This overwintering mechanism ensures the continuation of a thrips population, albeit low at certain periods, throughout the year.

Applications of pesticides for thrips control did not seem to reduce the population drastically. Migration of thrips into glasshouses complicates the problem of thrips control. The glasshouse in which this study was carried out was situated on a deciduous fruit farm on which *F. occidentalis* has been found outdoors. Harding (1961) found that destructive populations of *F. occidentalis* in onion fields develop mainly from build-up by breeding within the onion field, and secondarily from the migration of these insects. Based on this finding, one may assume that the thrips populations within the glasshouse were not primarily affected by populations outside. Badenhorst (1994) found similar peaks in thrips numbers in the glasshouse and in nearby orchards, indicating seasonal patterns unaffected by location of populations. The *F. occidentalis* population in the glasshouse may, however, be affected by human activities in the vicinity of the structure, for example, the mowing or removal of weeds in surrounding orchards. These practices may force interhost movement of the insects and consequent virus spread (Carter 1961). Plant species known to be potential hosts for the tomato spotted wilt virus (Chellemi *et al.* 1994) occur as cover crop in the orchards close to the glasshouse (*pers. obs.*). Chambers & Sites (1989) found that *F. occidentalis* was able to colonize a larger proportion of available wild plant species than other thrips species. The plant species infected by tomato spotted wilt virus in their study are similar to those found in South Africa and the assumption that these plants may act as hosts for the virus in South

Africa may be made. The grower should make every effort to screen all possible sites of entry into the structure in order to exclude these insects.

Due to the size of *F. occidentalis*, growers usually only become aware of their presence when feeding damage becomes visible, or when symptoms of the viral disease they transmit become evident. By this stage it is usually too late to begin applying control measures. Sticky traps provide more reliable monitoring of *F. occidentalis* than visual inspection of the plants. Sticky traps will also reveal attacks earlier, thereby improving control as proved in this study in 1992. As there is no reliable and on-the-spot method to determine whether thrips present in a greenhouse carry the virus or not, growers will have to continue applying control measures when the presence of these insects is detected.

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CHAPTER 4

EVALUATION OF TWO CHEMICALS ON THE WESTERN FLOWER THRIPS, *FRANKLINIELLA OCCIDENTALIS* PERGANDE, WITH LABORATORY BIOASSAYS.

4.1 ABSTRACT

The use of chemicals to manage western flower thrips (Frankliniella occidentalis) populations in commercial deciduous fruit orchards was highlighted in the 1994/95 season after high percentages of fruit were downgraded due to thrips damage. The efficacy of formetanate and endosulfan was investigated with residue-on-glass bioassays in the laboratory. Two separate strains collected from commercial orchards were tested. Both chemicals proved effective against test individuals under laboratory conditions. Fiducial limits (95%) for mean LC_{50}'s and LC_{90}'s for both chemicals on the two strains overlapped, indicating no significant difference in the susceptibility between the two strains to both chemicals. The results provide base-line data with which the susceptibility of other thrips populations may be compared. Two concentrations of each chemical are proposed as diagnostic doses for future resistance monitoring namely 280 and 840 ppm a.i. for endosulfan, and 6 and 75 ppm a.i. for formetanate. These doses achieved approximately 50% and 90% mortality, respectively. The method employed may be adjusted for chemical bioassay tests on a wide range of thrips species.

4.2 INTRODUCTION

The western flower thrips, *Frankliniella occidentalis* Pergande has, in the past decade, become a serious economic pest of many indoor as well as outdoor crops worldwide (Brodsgaard 1989). Studies by Immaraju *et al.* (1992) indicate that populations of *F. occidentalis* have built up resistance to four classes of chemicals commonly used in

California for the control of thrips in greenhouses. In South Africa, as in other countries, the control of this pest is of the utmost importance. Since its initial discovery in South Africa in 1987 on glasshouse crops (Giliomee 1989), it has spread to many outdoor crops (Daiber 1992, Gaum 1993). Oviposition sites on young Granny Smith apples and grapes develop into unsightly markings (Childs 1927, Madsen & Jack 1966, Yokoyama 1977) which decrease the value of such fruit destined for the export market. *F. occidentalis* has a broad host range and is thought to survive South African winters in apple orchards on plants in the cover crop (Chapter 1). As yet no biological control agents effective under outdoor conditions have been found. For this reason most farmers rely solely on chemicals for control. This increases the possibility of the development of resistance to chemicals commonly used in the field. A standardised bioassay technique that allows for rapid determination of resistance of thrips to chemicals would be valuable, so that alternative control procedures may be followed if necessary. Most researchers have made use of modified Munger cells (Munger 1942) containing treated plant material in order to evaluate compounds against adult and immature thrips (Morse & Brawner 1986, Morse *et al.* 1986, Freuler & Benz 1988, Immaraju *et al.* 1989, Zareh & Morse 1989, Immaraju & Morse 1990, Immaraju *et al.* 1990, Morse & Zareh 1991, Immaraju *et al.* 1992). Brodsgaard (1994) made use of the residue-on-glass application for the first time, testing chemicals on females of various strains of *F. occidentalis*. Advantages of this technique are that there is no need for fresh plant material, and, with necessary changes in food source, it can be used for the assaying of various thrips species. The Potter's Tower was used by most researchers and Robertson & Warner (1990) encourage its use as it simulates air-borne droplets as produced in field applications. Freuler & Benz (1988) used a similar method designed by Burgerjon (1956) in which leaf discs were placed on a rotating base while receiving the spray application.

Base-line data for chemicals proposed for thrips control will enable the monitoring of susceptiblity levels to these chemicals over time within certain populations, as well as

provide a reference for early detection of resistance in field populations. When determination of resistance of insects to chemicals is necessary, Halliday & Burnham (1990) suggest the use of one of three methods. One of these, the diagnostic dose test, is probably the most appropriate to monitor susceptibility when one is not certain that the dose will separate genotypes within a population. In this test one dose is used and the mortalities of susceptible and test strains compared. The authors suggest using two to three doses that kill between 50% and 95% of a susceptible strain.

In this study the effect of two chemicals was tested on field-collected strains of *F. occidentalis* in order to determine diagnostic doses for further monitoring of field populations.

4.3 MATERIAL AND METHODS

Two strains (A and B) of *F. occidentalis* were collected for testing in January 1995 (Table 1). Both strains originated from commercial apple orchards in which routine chemical thrips control programmes had been followed in the previous seasons. The orchards are situated in major deciduous fruit producing areas in the Western Cape.

Cover crop plants bearing the insects were collected early in the morning and placed in plastic collecting bottles sealed with gauze. The bottles were placed in chilled polystyrene containers and kept in a coolroom at 5°C. Experiments were carried out within 72 hours of material being collected.

Table 1. Collection sites and hosts of the two *F. occidentalis* strains tested.

STRAIN	COLLECTION SITE	HOSTS
A	Grabouw (34°12'S, 19°02'E)	*Rhaphanus raphanistrum* *Plantago lanceolata*
B	Vyeboom (34°04'S, 19°06'E)	*Rhaphanus raphanistrum* *Plantago lanceolata* *Sonchus* sp. *Malus domestica* (cv. Granny Smith)

A residue-on-glass technique similar to that described by Brodsgaard (1994) was used to test the effect of the chemicals. Modified coffin cells consisted of two glass plates (110x110x3mm) covering an aluminium frame (110x110x20mm). The aluminium frames had three holes drilled at intervals on each of two sides, which, excepting for one used for the food source, were covered by fine gauze material (104μ mesh size). The food source consisted of a cotton wool wick soaked in a 10% sugar solution. One of the holes was connected by a small length of pipe to a humidifier which ensured a constant source of humid air (55-80%RH) within the cells. Each cell was held together by tape, and formed a container with a volume of $242x10^3 mm^3$. Two units were set up, each consisting of six cells connected to a humidifier. These two units were placed in an incubator at a temperature range of 22-25°C and a photoperiod of 16:8 (L:D).

The top and bottom glass plates were sprayed with aqueous dilutions of the chemicals in a Potter's Tower at a pressure of 2 bar and with 1ml of the dilution per plate. After drying the cell was assembled and insects introduced. A test unit consisted of approximately 30 *F. occidentalis* females of random age per cell. Throughout the laboratory testing, females were selected as they are more important in colonization due to their ability to reproduce parthenogenetically. Each test included five dilutions of the

two chemicals tested and a control unit sprayed with distilled water similarly as described above. Mortality was assessed after 48 hours.

Two chemicals were tested. The first was the chlorinated hydrocarbon endosulfan (Thioflo SC, Hoechst, South Africa), in a 475g a.i./litre suspension concentrate. The second was the carbamate formetanate (Dicarzol SP, Schering, South Africa) in a 500g a.i./kg soluble powder formulation. Sugar was added at 2 grammes per litre to emulate field applications.

Data from the bioassays were subjected to probit analysis using the POLO computer program (Russel *et al.* 1977) to estimate LC_{50} and LC_{90} values and coefficients of the concentration-mortality regressions. The POLO program was also used to compare the results of assays on the two strains of test insects by means of the likelihood ratio test. This test evaluates the hypothesis that the concentration-response lines are equal (same slope and intercept) or parallel (same slope). Significant differences between the LC_{50} and LC_{90} values for the two populations were detected by non-overlapping 95% fiducial limits of each value.

4.4 RESULTS

Observations showed that the thrips moved readily on all the surfaces and fed from the sugar water wick. The results of the bioassays of the chemicals tested on two strains of female *F. occidentalis* are presented in Table 2.

Endosulfan: The LC_{50} value for strain B was lower than for strain A, while the converse was true for the LC_{90} values. These differences were not significant (Table 2). The LC_{50} values for endosulfan were 293.17 and 267.14 ppm a.i., while at LC_{90} they were 721.82 and 952.45 ppm a.i. for strains A and B, respectively. The slopes of both strains differed significantly ($P<0.05$) for endosulfan (Table 2, Fig. 1).

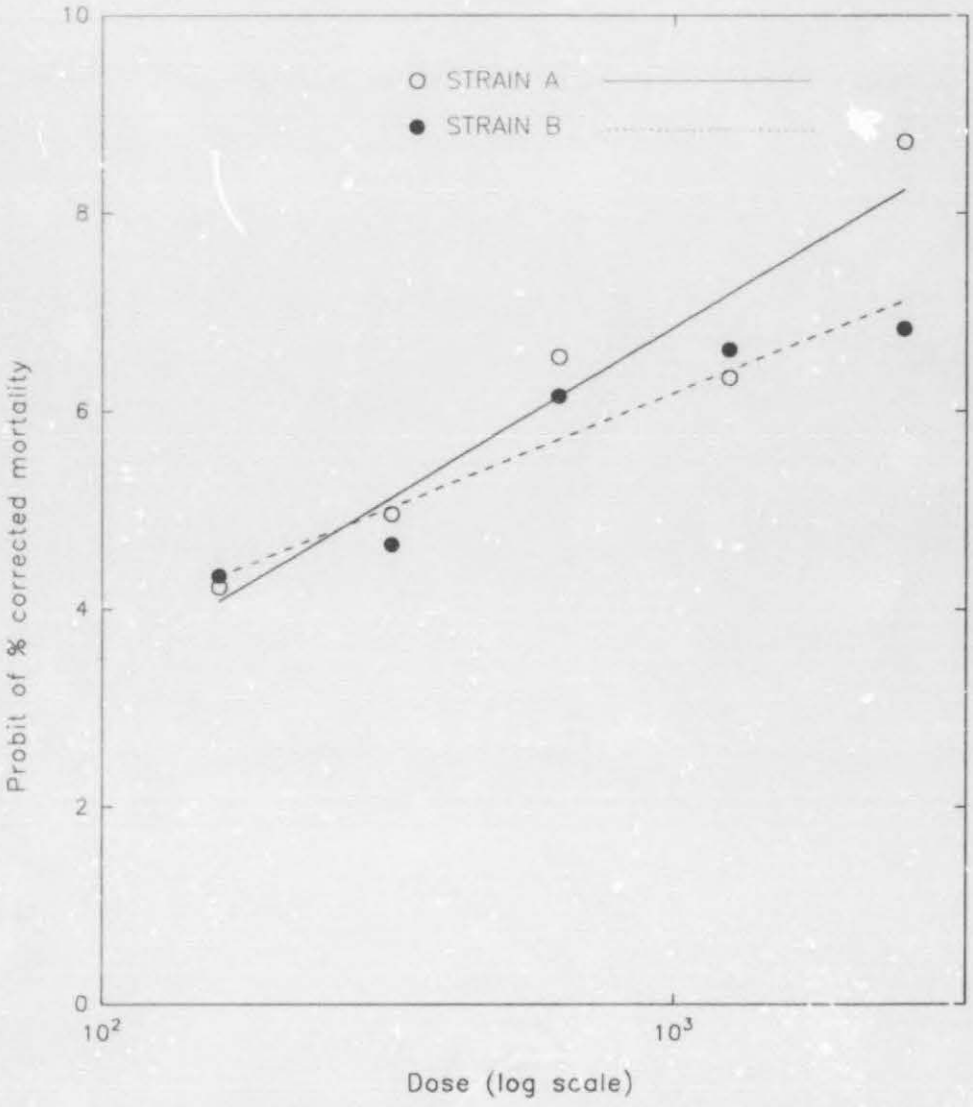

Figure 1. The weighted regression of log dose on percentage corrected mortality expressed as a probit for endosulfan tested in laboratory bioassays on female *Frankliniella occidentalis*.

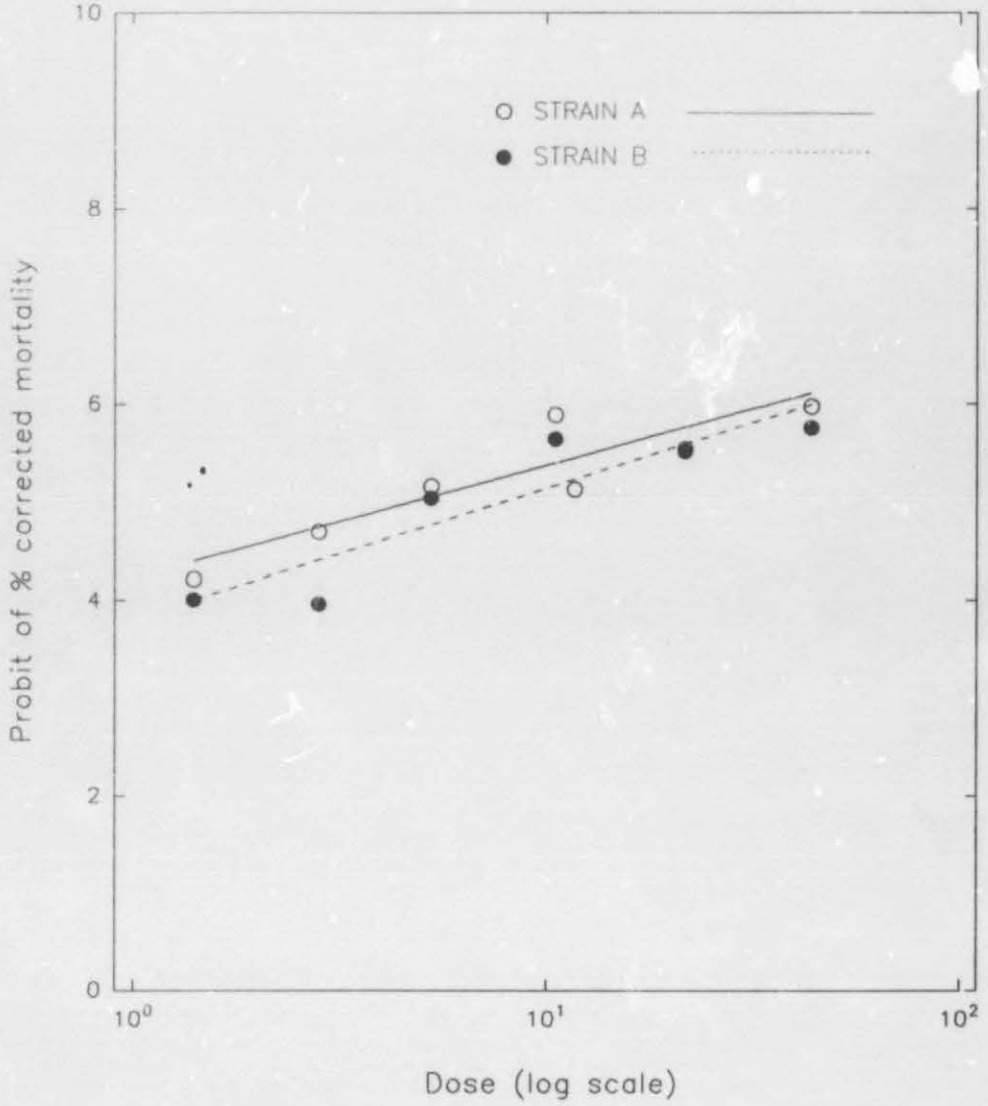

Figure 2. The weighted regression of log dose on percentage corrected mortality expressed as a probit for formetanate tested in laboratory bioassays on female *Frankliniella occidentalis*.

Formetanate: At both LC_{50} (7.34ppm a.i.) and LC_{90} (91.14 ppm a.i.) strain B was less susceptible than strain A (4.32 and 58.48 ppm a.i. for LC_{50} and LC_{90}, respectively), although these differences were not significant (Table 2). This chemical has only recently been registered for the control of thrips on deciduous fruit and was applied once in the field on both strains. The concentration-response lines from the two strains were parallel, indicating similar variability in response to formetanate (Fig. 2).

Table 2: The response of adult female *F. occidentalis* from two strains exposed to residues of two insecticides.

CHEMICAL	STRAIN	n	INTERCEPT (±SE)	SLOPE (±SE)	MEAN LC50 (ppm a.i.)	95% FIDUCIAL LIMITS	MEAN LC90 (ppm a.i.)	95% FIDUCIAL LIMITS
Chlorinated hydrocarbon (endosulfan)	A	702	-8.079 (0.718)	3.275 (0.271)	293.17	192.19-388.66	721.82	538.21-1174.27
	B	856	-5.632 (0.436)	2.321 (0.164)	267.14	174.81-359.93	952.45	686.36-1611.06
Carbamate (formetanate)	A	779	-0.719 (0.134)	1.132 (0.122)	4.32	1.254-7.99	58.48	25.96-556.23
	B	1037	-1.014 (0.136)	1.171 (0.115)	7.34	3.24-12.50	91.14	41.42-638.35

4.5 DISCUSSION

The bioassay technique used in this experiment proved successful, and with research into the feeding habits of other thrips species, and corresponding adjustments in the provision of food sources, this method may find application over a wide range of species as well as different life stages of thrips. Data variability and control mortality in this bioassay could be reduced if thrips of known and even age are used, while careful

standardisation of collection and bioassay procedures is needed to ensure reproducibility of results.

This residue-on-glass technique showed levels of toxicity of endosulfan in the two strains similar to that reported for another strain tested using an immersion trial method (Helyer & Brobyn 1992). The slopes of the probit lines for endosulfan in both strains were steep, reflecting low variation in the data. This compares favourably with a strain tested by Brodsgaard (1994) which was reared from a single mated female. This strain was thought to have reduced genetic variability regarding endosulfan resistance. Both strains in my study had been exposed to regular endosulfan applications for a period of at least five years, and it can be expected that the genetic response to endosulfan had been reduced over this time. In the study done by Brodsgaard LC_{50} values for endosulfan ranged between 156 ppm a.i. for the most susceptible population and 1245 ppm a.i. for the most resistant population. The values in the present study are similar to values of the susceptible populations tested by Brodsgaard. From these tests it appears that endosulfan is effective against the adult females of both strains of *F. occidentalis*. Very high populations of *F. occidentalis* built up later in the season in the orchard from which strain B was collected. This was not unexpected, as most growers spray insecticides for thrips control only during the full bloom to petal fall period which seems to be the most critical period in the season for damage by this pest (Madsen & Jack 1966) and not later in the season. Helyer & Brobyn (1992) reported that endosulfan does not affect *F. occidentalis* larvae. Therefore, if it is found that the high populations of *F. occidentalis* have minimal effect on the fruit and trees later in the season, chemical applications in order to curb their numbers are not necessary, and chemicals may be "saved" for outbreaks earlier in the season when fruit is susceptible to thrips induced damage.

Fields & Zwick (1978) researched the use of formetanate to control *F. occidentalis* in apples, and compared the results with those found using, among others, endosulfan

and DDT. Formetanate gave the best results in reducing pansy spot damage.

The aesthetic value of an export crop is such that no damage is acceptable. Thus insecticides are used regularly, without regard as to whether the pest is actually present. The ever-present threat of *F. occidentalis* developing resistance to these chemicals, as has been found in other parts of the world, however, must be kept in mind. Resistance is favoured by biological characteristics such as short generation times and many progeny (Georghiou & Taylor 1977). *F. occidentalis* also has a broad host range (Brodsgaard 1989) and is thus capable of detoxifying different plant toxins. This characteristic may provide the reason for their ability to detoxify insecticides. Heavy pesticide selection pressure is a major factor in the development of insecticide resistance (Georghiou & Taylor 1977). Brodsgaard (1994) and Robb & Parrella (1987) found that the resistance mechanism of *F. occidentalis* to classes of insecticides was quite stable over time. This means that growers cannot manage thrips resistance simply by withdrawing a chemical with the view to use it later. To postpone insecticide resistance in *F. occidentalis*, insecticides must only be sprayed when necessary.

Selection of a diagnostic dose is a useful approach for monitoring levels of resistance. It should represent a compromise between too low a value (one that could allow false detection of resistance) and too high a dose (one that would allow low levels of resistance to go unnoticed)(Rousch & Miller 1986). The rapidity with which thrips have developed resistance to insecticides (Immaraju *et al.* 1992, Brodsgaard 1994) indicates that early detection of resistance is essential if control strategies that could avoid strong selection for resistance are to be developed. The establishment of baseline data on the susceptibility of populations to chemicals will enable resistance to be monitored seasonally in populations and will also aid researchers to determine whether failures of chemicals were due to the development of resistance or due to faulty applications. It will also aid in the rapid diagnosis of any shifts in populations from various areas to insecticides commonly used in their control.

In the light of the above, two diagnostic doses for endosulfan, namely 280 and 840 ppm a.i., which result in approximately 50% and 90% mortality of the tested strains, are proposed. Similarly, diagnostic doses of 6 and 75 ppm a.i. are proposed for formetanate.

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CHAPTER 5

GENERAL CONCLUSIONS

When *Frankliniella occidentalis* was first identified in glasshouses in South Africa it did not take long to realize the cause of the problems experienced in many parts of the country. Within the first year of positive identification, this insect was found in apple orchards and many crops grown outdoors. It was probably present for some time before identification. Pansy spot on apples was photographed in South Africa as early as 1985, two years before *F. occidentalis* was identified from glasshouse crops, and five years before it was identified from an apple orchard. The reasons why it was not considered a pest before this time may be manyfold, including initial low levels of damage and incorrect damage identification. Pansy spot markings, for instance, were considered to be caused by hail until the insect's involvement was positively established.

Temperature is an important factor affecting population densities of *F. occidentalis* (Chapter 2). Life table studies showed that maximum population increase of this insect occurs at 25°C. As generation times tend to decrease with an increase in temperatures, this adds to the insects' capacity of rapid population build-up during summer in the western Cape Province when optimum temperatures are experienced. Longer generation times at lower temperatures also favour the over-wintering of *F. occidentalis* in the winter rainfall areas.

Studies investigating population dynamics and abundance of these insects in a glasshouse over a two year period confirmed the importance of temperature (Chapter 3). Populations were highest during the warmer months of the year. The ratio of males to females varies, with ratios biased towards females when populations are high. Male *F. occidentalis* are not affected by climatic conditions as are females. Threshold levels

for *F. occidentalis* have not been applied in glasshouses where the risk of viral transmission by this insect is high, and can prove disastrous if the virus is not detected in its initial stages. Even low numbers of *F. occidentalis* prove disasterous for virus transmission. It was found that yellow sticky traps are effective in monitoring thrips populations. As a result the grower was able to reduce the number of sprays applied, and apply these more effectively, by spraying according to monitoring data and not according to calendar dates as done previously.

F. occidentalis is difficult to control in many countries including South Africa. The relatively steep dose-response lines for two chemicals found in the bioassay studies in Chapter 4 may indicate that this insect is not yet resistant to the two chemicals. These studies must be repeated in order to determine the rate of resistance development in the field. Growers often apply control measures according to calendar dates, as mentioned above. This may lead to a rapid increase in resistance especially when sprays are frequently applied on small populations of the insect. Monitoring thrips populations, and applying control measures only when critical numbers of the insect are found may help to curb the development of resistance. As no baseline data for susceptible *F. occidentalis* populations are available in South Africa, two diagnostic doses for two chemicals are proposed. This will aid in the detection of resistance development at an early stage.

Other aspects which must be researched in order to promote more effective management of this insect are the biological control of *F. occidentalis* in the field, as well as investigating the use of resistant plant genotypes. The interaction of *F. occidentalis* with indigenous thrips species is another aspect which is important as *F. occidentalis* appears to displace indigenous thrips species when chemicals are applied. Where it is necessary to control this insect by means of chemicals, application techniques must be optimised in order to reduce the possibility of resistance development. As much is now known about the life cycle and population fluctuations of this insect, attention may also be focused on technology transfer and the encouragement of grower awareness of the pest at hand.